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MODE 1 DELAMINATION ANALYSIS AND ITS COMPARATIVE STUDY OF CARBON/EPOXY, GRAPHITE/EPOXY AND KEVLAR/EPOXY COMPOSITE STRUCTURES USING VCCT IN ANSYS

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ABSTRACT

In polymer composite materials manufactured using conventional hand layup technique is more prone to delamination. Delamination is one type of common failure observed in laminated composites. In present investigation delamination, due to opening mode (Mode-1) of a double cantilevered beam has been analyzed. A finite element method approach using ANSYS software is employed to determine the delamination, due to plane loading in addition to opening mode. Using CONTA and TAREGET meshing elements, determined the exact results of delamination. Understanding of delamination parameters was further extended, in terms of strain energy release rate, utilizing virtual crack closure technique (VCCT). To gain a better understanding of the origin of denomination fracture toughness, used modified beam theory to predict strain energy release rate of delamination in composite materials. All the analysis has been done for carbon/epoxy, graphite/epoxy and Kevlar/epoxy and compared.

KEYWORDS: Delamination, VCCT, Modified Beam Theory, Finite Element Method & Strain Energy Release Rate

Original Article

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INTRODUCTION

Polymeric fiber reinforced composites have been mostly accepted for primary structures in recent developed aircraft and aerospace vehicles such as the Airbus 380, Boeing 787 etc. Presence of delamination in composite structures will result in a reduction of strength, stiffness as well as fatigue life. Its growth can lead to the total failure of the structure. The aerospace industry is widely expanding its frontiers in the field of composites to take these advantages composite structures are made of laminating a sequence of thin layers together and those layers are oriented along the required direction of loading. Hence, understanding mechanism of delamination characteristics such as onset and growth becomes one of the important tasks in design. To quantify these behaviors of delamination, fracture mechanics are a common tool used in the study

The mode I delamination, facture toughness is usually measured using the double cantilever beam (DCB) test, which was standardized for fibre reinforced composites by ASTM D-5228 (1994), where the specimen specification are thickness is given by t, crack length a, and applied load P. The single point loading condition of the DCB provides the capability to use ordering based data reduction procedure, which is preferred because the only assumptions that must be made are of linear elastic behavior and of self-similar crack advance. Stable crack advance occurs under displacement-controlled loading, which makes continuous calculated of fracture toughness

with crack length feasible. Numerous examiners have deliberate free edge results in a finite width delaminated composite laminates subjected to uniaxial load, because of the adverse effect of delamination on the structural integrity. R. Hemanth and B. Naresh et al. [1] Comparison of glass fabric/epoxy matrix and carbon fabric/epoxy matrix composites have been made and the various parameters have been displayed in the form of graphs. This data is useful to choose the right material for the right applications for industries extensively using composites. Harikumar et al. [2] have studied the stress field, ahead of the delamination tip and the strain-energy release rate in uniformity composite laminates with mid-plane delamination cause, to mechanical and thermal strains with the help of a modified form of the Whitney-Sun theory. Haneef et al. [3] have taken out finite element analysis, to examine the delamination effect on composite structures with two models. Pagano et al. [4] assumed that, through the interlaminar normal stress is the main effect of delamination for polymeric material based structural composites. The basis of this assumption is a combination of experiments and stress analyses for laminates with dissimilar stacking sequences. Sarvestani [5] have confirmed an analytical method to exactly obtain the interlinear stresses near the free edges of usually laminated composite plates under the extension and bending. For the prevention of edge delamination, several techniques have been proposed, such as free-edge cap reinforcement as given by Heyliger et al [6]. Raju et al [7] has acquired SERR for edge-delaminated composite laminates using quasi three dimensional FEA and analyzed the complications of edge-delamination at the -35/90 interfaces of an eight ply [0/35/90] s, composite laminate subjected to uniform axial strain. Ye et al [8] has presented a representative model for delamination growth in composite laminates and a simple energy release rate model, for delamination growth is established. Krueger [9] has presented an overview of the virtual crack closure technique. Schelleken et al. [10] have simulated free edge delamination of uniaxial stressed layered specimens, using nonlinear finite element analysis. Venkatesha et al. [11] have presents a modified crack closure integral algorithm for four and eight-nodded iso-parametric quadrilateral elements, which can estimate the SERR components for various sizes of virtual crack extension by a single finite element analysis.

In view of above, it is clear that excellent studies have been made on strain energy release rate results. A comprehend therefore is required to be developed on the behavior of delaminated composite structures with and without wraparound study is motivated by a requirement to develop an understanding of the above given behavioral feature.

The present work aims at the studies of the strain energy release rate of double cantilever beams of three composite materials are carbon epoxy, graphite epoxy and Kevlar. Wraparound on the reduction of stress concentration at crack tip which leads to the crack propagation. Using virtual crack closer integral technique in ANSYS has been used to develop models for laminates (0/45/90/-45) s and perform Finite Element analyses and from ANSYS the results calculated strain energy release rate for three materials. Finally concluding that continuously applying loads on materials calculated their strain energy rates by using modified beam theory, although no formulation has been attempted in this study, an understanding of behavioral aspects of the delaminated composite structures is developed here.

Finite Element Method Description and Input Parameters

- CARBON/EPOXY
- GRAPHITE/EPOXY
- KEVLAR/EPOXY

In three cases stresses will be varied consequences and the results will be studied. The three material properties that are taken into account are as follows.

Table 2.1: Input Material Parameters

MATERIAL PROPERTIES	CARBON/EPOXY	GRAPHITE/EPOXY	KELVAR/EPOXY
Young's Modulus	E12(GPA)=164 E23(GPA)=12.8 E31(GPA)= 12.8	E12(GPA)=175 E23(GPA)= 7 E31(GPA)= 7	E12(GPA)=195 E23(GPA)= 14.6 E31(GPA)= 14.6
Poisson's Ratio	V12=0.32 V23=0.45 V31=0.32	V12=0.25 V23=0.01 V13=0.25	V12=0.30 V23=0.45 V13=0.30
Rigidity Modulus	G12(GPA)=4.5 G23(GPA)= 2.5 G31(GPA)= 4.5	G12(GPA)=3.5 G23(GPA)= 1.4 G31(GPA)= 3.5	G12(GPA)= 7.5 G23(GPA)= 5 G31(GPA)= 7.5

Mode -1 Loading

Input Parameters

- Number of areas: 2 in number overlapping each other
- Fibre orientation in the plate: [0/+45/90/-45]
- Number of layers in each plate: 4
- Load applied: 1N-100N with a variation of 0.5N
- Direction of load applied: Perpendicular to the area.

Finite Element PARAMETERS

- Element type1: SOLID 185.
- Element type2: Targe 170.
- Element type3: Conta 174.

Series of Steps for Modelling and Analysis

The process required to make a virtual model involves the following steps:

Modeling

DCB: Two areas will be modelled with 100 mm length and 3mm width. One will be modelled above the x-axis and another one below the x-axis, but both have to overlap each other. It's a sectional view will contain a fiber orientation of [0/+45/90/-45] T. For all materials analysis is done area meshing on Conta element.

Analysis and Meshing

It is the main of the process where all the parameters are assigned to the model for meshing. Using these parameters results can be tabulated and observed. DCB loading: Area mesh is taken with an optimum element size of 5. The material properties are taken as taken above three composites respectively. The additional initial crack length is set between both the overlapped areas up to 0.75 percent of the original area that is prepared to modelled.

Applying the Load Specification

In Double cantilever beam specimen loading conditions are different applying loads from 0.5 to 100 N in steps of 0.5 N.

Solving using ANSYS

In this analysis process, check the various element types that have been given out, various material Properties that have been taken into account and various loading conditions applied in this case. These will generate a series of solutions to get the optimum solution for all the values applied will give us the desired result. These optimum solutions are calculated using a series of equations that will meet at a point to give the best output.

The coding and programming in Ansys is taken from the references Finite element and analysis of VCCI technique of composite materials.

METHODOLOGY

Interlamainar Fracture Toughness Formulae and Calculations

Three data reduction techniques for calculating the energy release rate (G) values have been evaluated. They consist of Modified beam theory (MBT).

Modified Beam Theory (MBT) Method- The beam theory expression for the strain-energy release rate of a double cantilever beam

$$\boldsymbol{G} = \frac{3\delta \mathrm{P}}{\boldsymbol{2aL}}$$

This expression will overestimate G1 because the beam is not perfectly built. One may have to correct this rotation to treat the specimen DCB as if it contained a slightly longer delamination C^$\frac{1}{3}$ as a function of dissemination length. The compliance C, is the ratio of the load point displacement of the applied load □/P. The values used to generate this plot should be the load and displacements corresponding to the visually observed delamination on section the edge and all propagation values.

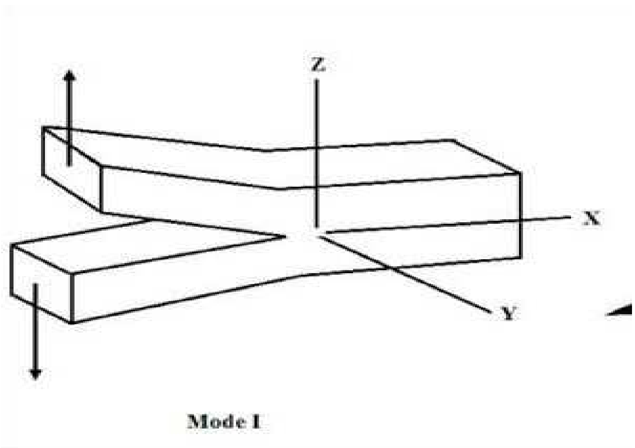

Figure 4.1.1: Mode 1 Delamination

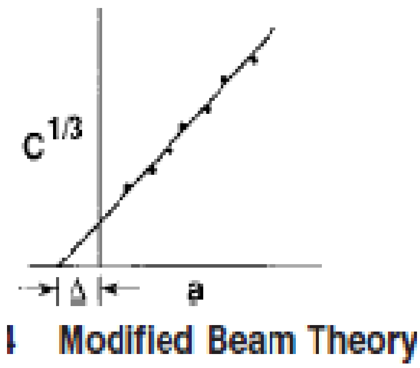

Figure 4.1.2: Modifier Beam Theory Results

RESULTS AND DISCUSSIONS

Results of DCB Taken from Ansys Pictures

Carbon/Epoxy

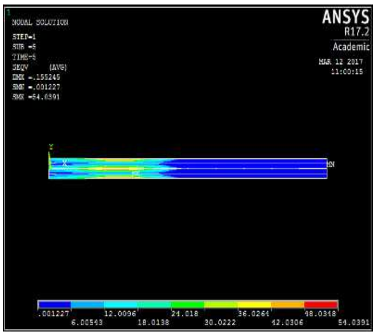

Figure 5.1.1(a)displacement at 5N

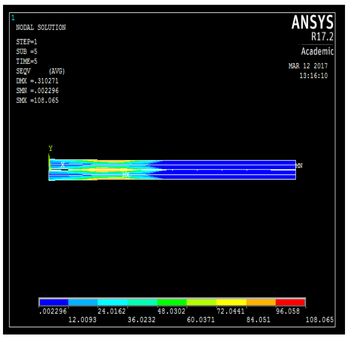

Figure 5.1.1(b) displacement at 10N

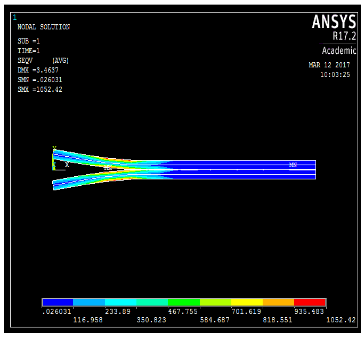

Figure 5.1.1(c) displacement at 100N

Graphite/Epoxy

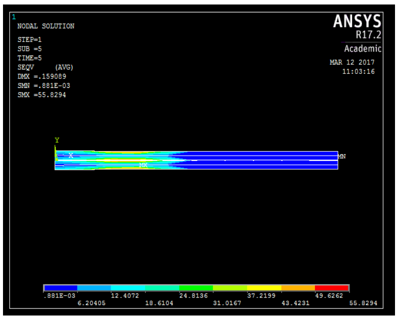

Figure 5.1.2(a)displacement at 5N

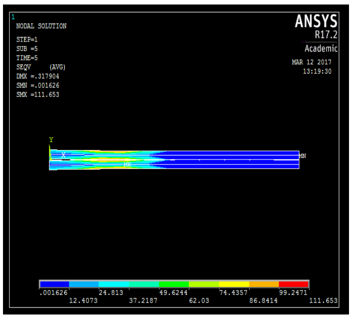

Figure 5.1.2(b) displacement at 10N

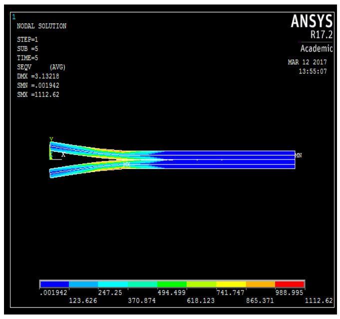

Figure 5.1.3(c) displacement at 100N

Kevlar/Epoxy

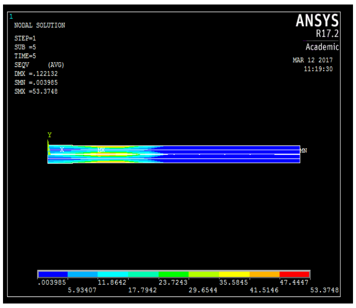

Figure 5.1.3(a)displacement at 5N

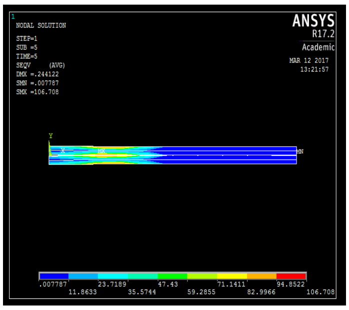

Figure 5.1.2(b) displacement at 10N

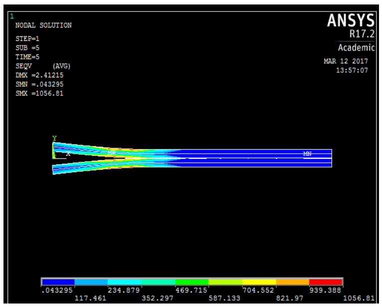

Figure 5.1.3(c) displacement at 100N

From the above figures we can observe that the variation of crack length (a) and displacement (d) would be identified by processing in ANSYS from the modified beam theory. The loading conditions delamination case has been increased by a difference of 0.5 upto 100N and the following results have been taken images and tabulated. From the figures, highest crack length would be observed in graphite epoxy and lowest in Kevlar epoxy, by applying related loading conditions mentioned above considerations.

Tabular Results of Epoxy Composite

Static DCB testing was run for a number of initial crack lengths for both carbon-epoxy, graphite epoxy and Kevlar

epoxy composite specimens. Results were recorded and compiled for use in calculating the strain energy release rate of each sample type by using ANSYS software. The load vs. strain energy release rate opening displacement chart for all specimens with various initial crack length is shown in Figure 5 as a reference. Similar plots were also generated for CG-Ep specimen. Samples were gradually loaded to the critical load limit was reached, then unloaded. This loading cycle was repeated for each initial crack length to produce a reliable delamination profile for each DCB specimen.

CARBON

Table 5.2.1: Results for Load Vs Strain Energy Release Rate of Carbon Epoxy Composite

LOAD P (N)	CRACK LENGH a(mm)	DISPLACEMENT D(mm)	STREE (N/mm^2)	STRAIN NERGY(G)
0.5	0.5	0.01553	5.404	0.001165
1	1	0.031066	10.8087	0.00233
2	1.5	0.0621	21.6169	0.00621
4	2	0.124	43.2322	0.0186
8	4.6	0.243	86.3449	0.031696
10	8.8	0.310	108.065	0.02642
30	13.8	0.928	323.962	0.151304
50	23.5	1.5420	593.359	0.246064
70	25.1	2.155	753.142	0.450747
100	27.5	3.4637	1052.42	0.944645

GRAPHITE

Table 5.4.2: Results for Load Vs Strain Energy Release Rate of Graphite Epoxy Composite

LOAD P (N)	CRACK LENGH a(mm)	DISPLACEMENTD(mm)	STREE (N/mm^2)	STRAIN ENERGY(G)
0.5	0.5	0.0159	8.5885	0.001315
1	1	0.03184	11.1662	0.00466
2	1.5	0.0636	22.3323	0.00621
4	2	0.127	44.6639	0.0186
8	4.8	0.251	89.3243	0.030375
10	18	0.317	111.653	0.012917
30	14.8	0.950	350.254	0.141081
50	23.5	1.488	557.714	0.246064
70	25.2	2.203	780.191	0.448958
100	28	3.132	1112.62	0.8389

KEVLAR

Table 5.2.3: Results for Load Vs Strain Energy Release Rate of Kevlar Epoxy Composite

LOAD P (N)	CRACK LENGH a(mm)	DISPLACEMENT D(mm)	STREE (N/mm^2)	STRAIN ENERGY(G)
0.5	0.5	0.121	5.3392	0.0009
1	1	0.026	10.6782	0.00195
2	1.5	0.048	21.3547	0.0048
4	1.8	0.09	34.945	0.015
8	4.8	0.1953	85.2357	0.024
10	15	0.244	106.708	0.0122
30	14.8	0.730	319.586	0.11
50	22	1.214	531.552	0.2069
70	23	1.695	792.284	0.38
100	27	2.41	1056.81	0.669

The initially applying load condition would be 0.5N and corresponding strain energy release rate would be identified by processing in ANSYS from the modified beam theory. The loading conditions delamination case has been increased by a difference Of 0.5 N to 100N, and the following results have been tabulated. From the above tabulated results, comparing three given are Carbon Graphite and Kevlar materials for this epoxy Kevlar/epoxy having lowest strain energy release rate and less crack length.

Graphs for Different Loading Conditions Vs Crack Length

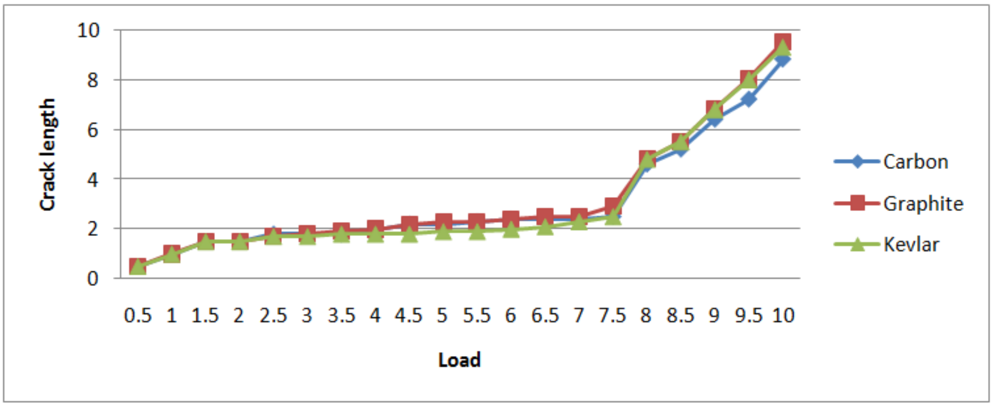

Figure 5.3.1: 0.5-10N Load Vs Crack Length

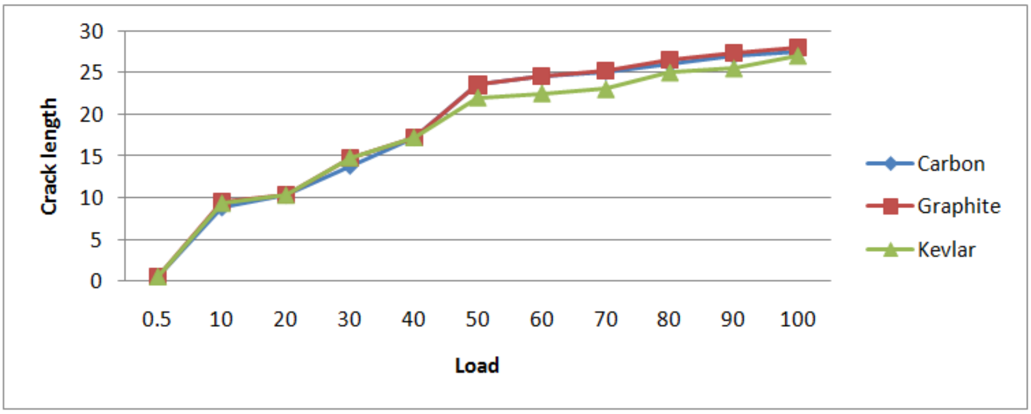

Figure 5.3.2: 0.5-100N Load Vs Crack Length

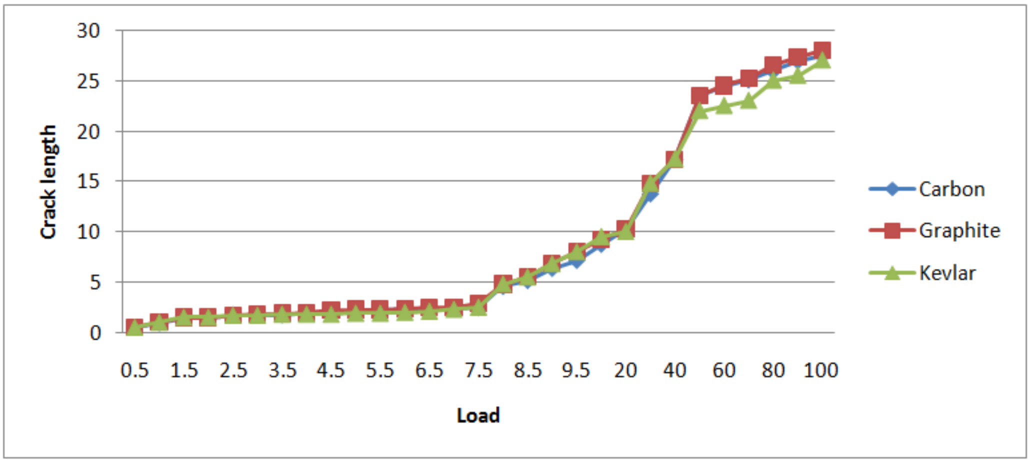

Figure 5.3.3: 0.5-100N Load Vs Crack Length

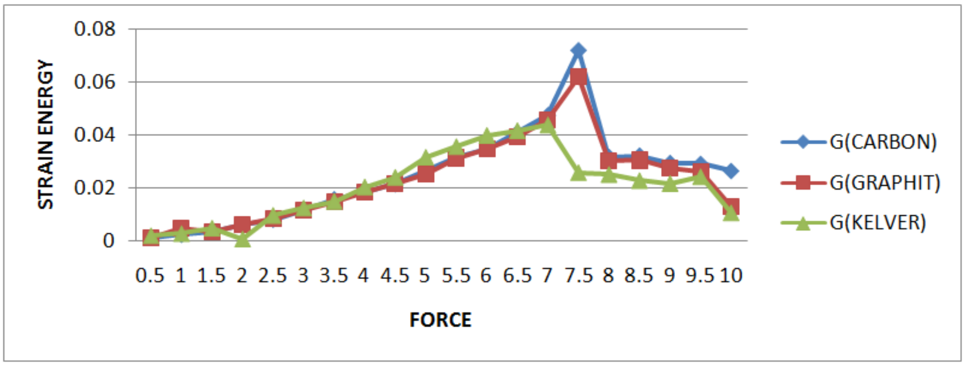

Figure 5.3.4: 0.5-10N Force Vs Strain Energy

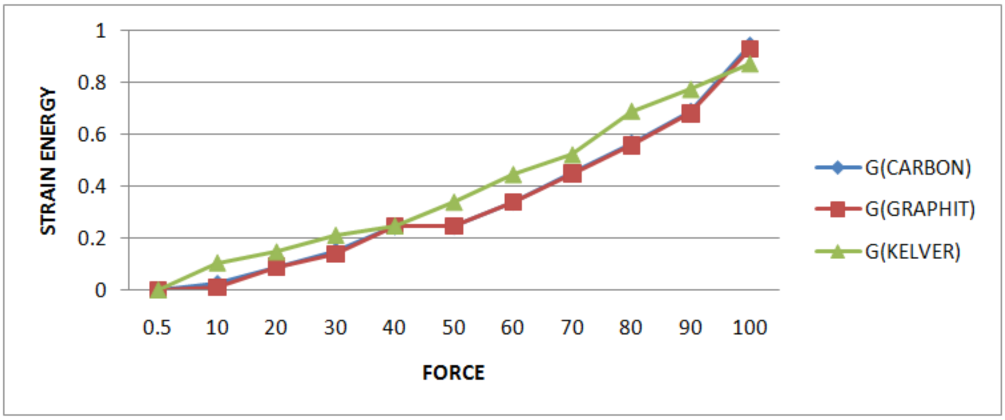

Figure 5.3.5: 0.5-100N Force Vs Stain Energy

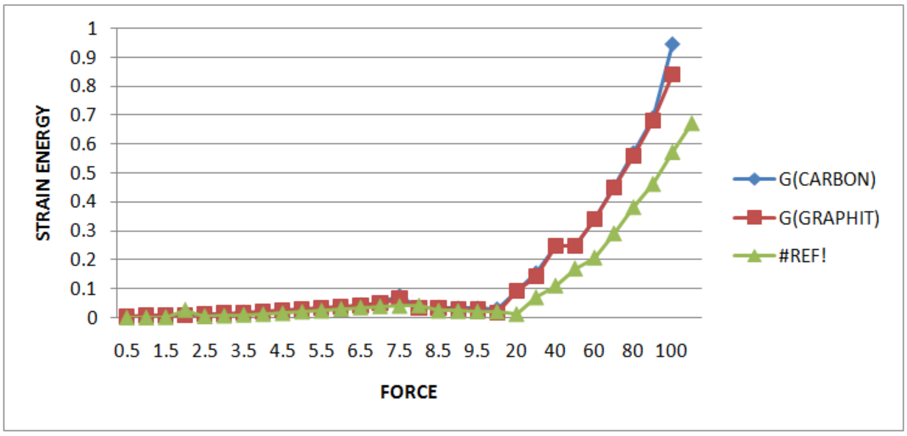

Figure 5.3.6: 0.5-100N Force Vs Strain Energy

From the above graphs loading conditions delamination case has been increased by a difference Of 0.5 N and the following results calculated. The results are plotted on a graph for variation of load verses strain energy release rate for the three materials which have taken. The initially applying load condition would be 0.5N and the corresponding displacement would be identified by processing in ANSYS from the modified beam theory. Above graphs clearly showing behaviors by giving epoxy materials with strain energy release rates where the values would change with respect to loading conditions. So that figures are given in step of different loads in steps are 0.5N, 10N and total values considered. Finally the results are showing that Kevlar/epoxy having lowest strain energy release rate and less crack length.

TERMINOLOGY

- P= load
- δ=load point deflection
- b=specimen width
- G1= Energy Release Rate
- a= initial crack length
- E12=Young's modulus in X direction
- E23=Young's modulus in Y direction
- E3=Young's modulus in Z direction
- V12=Poisson's ratio in xy direction
- V23=Poisson's ratio in yz direction
- V13=Poisson's ratio in xz direction
- Gxy= Rigidity Modulus in xy direction
- Gyz= Rigidity Modulus in yz direction
- Gxz= Rigidity Modulus in xz direction

The loading conditions delamination case has been increased by a difference Of 0.5 N and the following results have been tabulated. The results are plotted on a graph for variation of load verses strain energy release rate for the three materials which have taken. The initially applying load condition would be 0.5N and the corresponding displacement would be identified by processing in ANSYS from the modified beam theory.

CONCLUSIONS

The current paper has shown that he critical strain energy release rate (*G*) values for mid-plane delamination in DCB specimens composite epoxy material have been presented in this paper. The *G* values have been determined finite element analysis. Finite element analysis was carried out using ANSYS with composite solid elements as well as 20-node solid elements. The critical strain energy release rate values of three materials computed by VCCI Technique FEM analysis and compared results.

From the results have drawn the graphs and evaluating that increasing the load conditions crack propagation length will increase for three materials having different crack lengths. From the graph Kevlar composite having lowest crack length compared to carbon and graphite epoxy materials. It leads to Kevlar having lowest critical strain energy release rate. Finally concluding that Kevlar has a high fracture resistance capacity compared to carbon and graphite composite it is observed in tabulated results and pictures shown in this paper

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